BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: ALSEP Status Report - Case 340

DATE: March 6, 1969

FROM: W. L. Piotrowski
G. K. Chang
P. J. Hickson
M. T. Yates

ABSTRACT

The current status of ALSEP is reviewed and problems which have recurred in the ALSEP system and subsystem tests are detailed.

ALSEP Array A has been successfully tested and the flight unit, designated ALSEP I, has been accepted by NASA and is in storage at Bendix Aerospace Systems Division (BxA) awaiting rework of the PSE caging subsystem. ALSEP I is scheduled for shipment to KSC in mid-March, 1969.

Array B (ALSEP III) has completed flight acceptance testing and has been accepted by NASA. ALSEP III is in storage at BxA awaiting rework of the multiplexer and resolution of the drill problem before shipment of the unit to KSC for inclusion on the third lunar landing mission. Array C (ALSEP IV) is undergoing qualification testing and is scheduled for delivery in April, 1969.

The recurrent ALSEP problems and the steps being taken to resolve them are summarized in Table A.

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MEMORANDUM FOR FILE

I. INTRODUCTION

With the deletion of ALSEP I (Apollo Lunar Surface Experiments Package) from the first lunar landing mission (G-1), NASA management attention has necessarily focused on the development of the replacement science package for G-1, the Early Apollo Science Experiment Package (EASEP). Work on ALSEP has continued close to schedule (ALSEP I is scheduled for the second landing, ALSEP III for the third, and ALSEP IV for the fourth) but rework of some subassemblies has delayed shipment of these units to KSC.

The intent of this memorandum is to review the current status of ALSEP and to bring attention to problems which have recurred in the ALSEP system and subsystem tests. Although the recurrent problems are few and probably not serious enough to exclude ALSEP from any mission, considerable effort is currently being expended to resolve them.

The ALSEP is a multi-disciplinary, astronaut-deployed group of scientific experiments and support subsystems which will be emplaced on the Moon to monitor lunar physical and environmental characteristics. ALSEP has a design life of one year and a maximum (timer-limit) life of two years. It is desirable to have a net of at least three widely separated ALSEP's operating simultaneously on the lunar surface to obtain seismic triangulation.

Each ALSEP Array consists of three major components:

1. Radioisotope Thermoelectric Generator (RTG) which develops electrical power by thermoelectric conversion.

Table A

Item	Diagnosis	Product Fix	Due
C/S Multiplexer Transistor Failure	faulty encapsulation	replace with high reliability equivalent components	ALSEP III and IV not ALSEP I
C/S Timer Failure	faulty indexing wheel materials and faulty lubrication	new timers being qualified (uses other materials and lubricants)	March
PSE caging subsystem	deficiencies in manufacturing techniques	rework of caging subsystem	Flight 1 Early March
PSE thermal control	inadequate for rock moon	possible improvement by specifying a more complex deployment procedure. Independent evaluation at ADL.	March
LSM sensor flipping and gimbaling mechanism intermittent	unknown	under evaluation at ARC	March
SIDE/CCGE arcing	outgassing	extended outgassing time before high voltage turn-on	N/A
HFE drilling task	hardware OK, Astronaut office believes drilling task to be too complex	new drilling approach under study at MSC	March
ASE mortar box survival	needs lifetime test	not in testing schedule	not scheduled
CPLEE amplifiers inoperative or intermittent	faulty components	under analysis at BRL	March

2. Central Station (C/S) which distributes power from the RTG to the experiments and subsystems, receives and decodes uplink commands, collects and transmits down-link scientific and engineering data, and provides timing and control of experiment subsystems. Also mounted on the C/S is a dust detector consisting of three orthogonally mounted solar cells plus thermistors to monitor any accumulation of dust.

3. One of the experiment arrays as shown in Table I.

Bendix Aerospace Systems Division (BxA) is the prime contractor for ALSEP. The various experiments are either built under subcontract to BxA or supplied to BxA as GFE (Government Furnished Equipment).

ALSEP is transported to the Moon in the two compartments of the LM Scientific Equipment (SEQ) bay and in the fuel cask mounting assembly located outboard of the LM adjacent to the SEQ bay. Unloading and deploying ALSEP approximately 100 meters from the LM is estimated to take 1 1/2 man-hours.

II. SYSTEM TESTS

There are three levels of ALSEP system tests: the prototype test, the qual model test, and the flight unit acceptance test. The objective of the prototype test is to verify the design of the C/S and the compatibility of the experiment subsystems. The aim of the qual model test is to ensure that the system meets the Apollo spacecraft structural requirements and that all systems will operate in the lunar environment as an integrated unit. The goal of the flight acceptance test is to ensure that the flight hardware has met all the Apollo spacecraft requirements and is ready for operation on the lunar surface. (At no time during the systems tests are the experiments checked to verify that they will do anything other than respond to C/S commands and survive the lunar environment.) Each level of system tests consists of the following:

1. Initial Integrated System Test

2. Crosstalk

3. System Electromagnetic Interference

4. Central Station Power Dissipation

5. Vibration
6. Acceleration
7. Shock
8. Mass Properties
9. Magnetic Properties
10. Thermal/Vacuum

In the Array A configuration, the prototype, the qual model, and the flight hardware were subjected to all the tests listed above. All tests of this configuration (including ALSEP I and II* flight systems) were completed and the units accepted by NASA in October, 1968 with the exception that several discrepancies must be resolved before shipment of ALSEP I to KSC in March 1969. (These discrepancies are discussed in Section III.)

The Array B prototype hardware was a rework of the Array A prototype system with a few modifications and the replacement of the necessary experiment subsystems to conform with Array B as shown in Table I. The prototype B tests were completed in October 1968.

Due to financial constraints, the proto B system was then refurbished to be the qual B hardware. The qual B system tests were completed in January 1969. ALSEP III (Array B) has completed flight acceptance tests and was accepted by NASA in February. In Array C, the Active Seismic Experiment (ASE) is the only subsystem which has not previously been integrated in either Array A or B, and therefore the Array C system tests will deal solely with the ASE. The qual C system tests were started in January and the ALSEP IV (Array C) flight acceptance tests started in mid-February. All ALSEP system tests are expected to be completed by May 1969.

III. SUBSYSTEMS

A. Radioisotope Thermoelectric Generator (RTG)

The RTG, consisting of a Power Generator Assembly and a fuel capsule, provides electrical power for operation of ALSEP on the Moon. The fuel capsule fits into a central cavity of the Power Generation Assembly where the thermal energy generated

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*ALSEP II has been cannibalized to build the EASEP PSE for inclusion on G-1. Therefore, ALSEP II is no longer a flight system although the flight unit instruments (except for the C/S and the PSE) are still available for other uses.

by α-particle decay of Pu^{238} is converted to electrical energy by the thermopile. The RTG provides approximately 66 watts at 16 volts to the Central Station where the 16 v input is converted to the six ALSEP operating voltages and distributed to the subsystems.

The RTG has been developed and tested by General Electric (GE) under contract to the Atomic Energy Commission (AEC) and the unit is delivered to NASA as a flight qualified instrument. RTG problems that occur are the sole responsibility of AEC and none remain unresolved at this time. Deliveries of the RTG are on time (Mod 19 and Mod 21 have been accepted as part of ALSEP I and ALSEP III respectively) and proceeding on schedule. Tested power performance has been above initial guarantees.

NASA interfaces with the RTG are: (1) the tie-down points for the Power Generation Assembly to ALSEP/subpack 2, (2) the cask attachment points to the LM, (3) operational interfaces, including KSC fuel storage and on-pad loading in the cask, on-pad cooling of the cask, and fuel transfer on the Moon. Currently, there are no problems on the NASA side of the interface.

A safety analysis of the fuel capsule delivery system (the graphite cask, dome removal tool, fuel transfer tool, etc.) has been performed with data inputs from GE, AEC, and NASA. NASA inputs to the safety analysis are in the form of reference trajectories, abort modes and their probability of occurrence, and mission requirements. The Safety Analysis Report (SAR) is currently being reviewed by an interagency panel (NASA, DoD, and AEC) which will evaluate the SAR and flight approval will be requested if the system is deemed safe.

The fuel capsule design is such that about eight years after fuel encapsulation the helium gas build-up causes the capsule to rupture along a scored section resulting in controlled gas leakage through filters. This controlled leakage does not impair the operation of a fuelled RTG. Since the fuel capsule deliveries are essentially complete, re-encapsulation of the fuel is not necessary for RTG's flown before 1974. Since ALSEP can use, and actually counts on, surplus power for semi-active thermal control, power losses due to fuel decay (about 1.6%/year) results in reduced power margins and enrichment of the fuel after several years storage may be warranted.

B. Central Station (C/S)

The C/S distributes power from the RTG to the experiments and subsystems, receives, decodes, and applies uplink commands, and collects, processes, and transmits scientific and engineering data from the experiments to the MSFN.

The C/S electronics are contained within subpackage one. Passive thermal control is provided by the thermal plate, sunshield, side curtains, and reflectors. Semi-active thermal control is provided by commandable heaters. The sunshield also provides pre-deployment mounting for some experimental subsystems and post-deployment mounting for the dust detector.

The design of the C/S and compatibility of the C/S with the experiments has been verified in the prototype systems test. The operation of the C/S and reception, decoding, and application of uplink commands under simulated lunar environmental conditions has been verified during the IST (Integrated Systems Test) on the qual models and on the ALSEP flight units. The thermal tests were carried out under "ideal" conditions (white paint and no dust) and also at a simulated solar input 25% above nominal to simulate thermal paint degradation and dust. The C/S flight units are subjected to tests similar to those undergone by the qual model.

During the systems level tests, only one component in the C/S, the timer, has experienced recurrent problems. However, during subsystem component level testing six C/S analog multiplexers have failed.

1. C/S Analog Multiplexer

The analog multiplexer/converter and digital data processor are the two physical components comprising the C/S data processor. Digital data from the experiments is applied directly to the processor channels. Analog engineering (housekeeping) data is routed to the 90-channel analog multiplexer and through a buffer stage to the A/D converters. The digitized output data is applied to the digital multiplexer where it is gated and presented to a shift register which accepts either experiment or housekeeping digital data. The data processor then formats the data into a telemetry format for transmission to the MSFN.

Two components within the 90-channel multiplexer have experienced numerous failures in subsystem component level tests but only one failure has occurred during systems level tests. (No multiplexer failures have occurred during prototype, qualification, Flight 1, 2, or 3 systems tests.) The two generic part types which have exhibited recurring failure modes are:

a. FET semiconductor - a common failure mode is a short or low junction breakdown voltage between the gate and source or gate and drain.

b. PNP Transistor - two common failure modes are excessive leakage current or open circuit across one of the junctions.

Both devices are plastic encapsulated pallet T-paks. Preliminary failure analysis reports from NASA/ERC (Electronics Research Center) indicate the failures are due to faulty encapsulation.

An industry survey to find a suitable replacement part which met volume, electrical, and reliability constraints resulted in the selection of a Motorola ceramic, hermetically sealed transistor. The analog multiplexers on ALSEP III and IV and EASEP will be reworked by replacing all nine circuit boards containing the defective type FET and PNP devices with circuit boards incorporating the Motorola transistor chip. The present rework timetable does not include replacement of these parts in the ALSEP I. MSC states that requalification of the multiplexer will not be required.

The analog inputs to the multiplexer consist only of housekeeping data, and consequently, the loss of some data channels would not degrade the scientific return from ALSEP (except in those cases where housekeeping data may discern abnormalities within the experiment).

2. <u>C/S Timer</u>

The Central Station timer provides predetermined switch closures used to initiate specific functions within ALSEP and the data system when the uplink is unavailable for any reason. The C/S timer consists of a Bulova Accutron clock (Model TE-12) and a mercury cell battery. The timer starts to provide back-up timing pulses and switch closures when the power cable is mated to the C/S on the lunar surface. The switch closures are at one minute, 12-hour, and 720-day intervals. The one-minute and 12-hour closures are continuously repetitive; however, the 720-day closure occurs only once and permanently turns off the ALSEP transmitter.

The ALSEP timer has experienced a series of failures which are listed below:

a. During an early evaluation test in a vacuum environment the timer ceased to operate after a period of 9 days. Examination of the timer revealed the problem to be a metal-to-metal seizure of the commutator and brush system in the one minute switching mechanism. Subsequently, the commutator was coated with Epon 823 with a catalyst. In addition, a Nylasint 64HV-2 chip was impregnated with Dow-Corning 704 silicon oil and installed adjacent to the brush-to-commutator contact area to provide a lubricant to the commutator. The modified timer operated satisfactorily for 3622 hours in a run mode.

b. Further tests of the timer in a vacuum environment revealed an outgassing of the lubricant (a moebius syntalube oil), used in the Accutron jewels. The moebius syntalube oil was later replaced with Dow-Corning FS 1265. Test data indicate that the performance of FS 1265 in a vacuum environment is excellent.

c. To preclude the possibility of cold welding or seizure of the index finger and the index wheel, a small amount of Dow-Corning FS 1281 was applied to the spokes of the index wheel. The application of this lubricant resulted in the accumulation of contaminating material on the wheel. A breakdown of the silicon lubricant was believed to be a possible contributive factor.

d. In order to fully evaluate and resolve the wheel lubricant selection, Bulova supplied BxA with 56 Accutron movements, three lubricants, and several index wheel materials to be tested in various environments. The evaluation test of the 56 mechanisms at BxA revealed eleven functional failures.

e. The materials and lubricants were then sent to the KSC Mulfunction Analysis Lab for evaluation. KSC recommended that Palliney 7 material be used for the index wheel; that Krytox lubricant be used for the wheel jewels; that the neoprene O-rings be replaced with Viton O-rings; and that the teeth of the index wheel be kept free of lubricants. The Flight 1 timer was reworked using these materials. Qualification testing of the reworked timers including thermal-vacuum cycling for 36 cycles will be done on two reliability models in parallel with the rework of the other flight units. (This is necessary in order to meet the March shipment of ALSEP I to KSC.)

The failure of the timer alone would have little impact on the experimental data since only the timing pulses for automatic sequencing of the experiments would be lost and these could be supplied by uplink commands. The failure of both the timer and loss of the uplink command capability would result in an ALSEP which would continuously transmit until the transmitter failed or power was lost. However, double failures of this type are unlikely and no contingency planning has been done for double failures.

C. Passive Seismic Experiment (PSE)

The objective of the PSE is to measure the motion of the lunar surface in three broad frequency ranges: short period seismic energy from 0.2 to 35 Hz; long period seismic energy from 0.3 to 250 sec period; and tidal deformations with periods of a month. In order to sense these motions the PSE contains two horizontal swinging gate long period seismometers, one vertical La Coste suspension long period seismometer, and one vertical short period seismometer. Feedback loops used to center the masses in the long period instruments are monitored to provide a measure of the lunar tides (vertical component of gravity and horizontal tilts). In addition, the internal temperature is monitored to allow accurate determinations of the spring constants in situ.

Teledyne (subcontractor to BxA for the PSE) met the design goals for minimum detectable signals: 1 nm (long period) and 1 nm at a frequency of 1 Hz (short period). Design goal for minimum detectable tidal signal (8 μgal) was met, and the specified 80 db analog dynamic range for the seismic outputs was also achieved. In general, the sensors and their associated electronics have proved to be satisfactory.

The PSE subsystems for which there has been continuing concern are thermal control, including shroud and temperature controller circuit, and caging, including pressure distribution manifold, bellows, and the uncage circuit.

1. <u>PSE Thermal Control</u>

The PSE thermal control subsystem is unique among ALSEP experiments in that it utilizes a portion of the lunar surface for a heat sink and is designed to control the temperature excursions of that portion of the Moon under the thermal blanket (a 5 foot diameter circle). This is in contrast to the thermal design of other experiments which attempts to completely decouple the instruments from the lunar surface. The rationale for thermally controlling the lunar surface was originally based on the desire to get good tidal data which would be compromised by possible thermally-induced motions of the surface if the temperature swing were not reduced.

The implementation of this concept consists of a top hat-shaped multilayer super insulation blanket, the crown of which covers the sensor while the brim extends out over the lunar surface. Inside the sensor is a 2.5 watt thermostated heater in addition to a constant 0.65 watts dissipation from the sensor electronics (most of the PSE electronics are located in the C/S and do not contribute to the thermal load within the sensor). The 2.5 watt heater is held full on if the temperature is below 124° F. From 124° F to 125° F the heater is proportionally controlled and should the temperature rise above 125° F the heater is off. This automatic thermostat mode can be commanded off and the heater controlled by ground command.

The specification on heat loss through the thermal shroud at its nominal operating point is 0.60 watts. Tests conducted in late 1967 gave measured values around 1.5 watts. Analysis of the test configuration indicated that from one half to two thirds of this heat loss may have been due to leaks through the instrumentation cables and fixtures, and therefore, the intrinsic heat leak through the shroud was from 0.75 to 0.5 watts. Shrouds that had been subjected to vibration and shock showed similar results.

Design verification testing of the PSE thermal control system was carried out in early 1968. Analysis of the results showed that the thermal control system could maintain a temperature difference of up to 75 to 85° F between the sensor and the simulated lunar surface. This is adequate for an insulating ("dust") Moon, the expected case, where a temperature difference of only 20° F would be required. However, for a conducting ("rock") Moon, temperature differences of the order of 130° F may be necessary to maintain the 125° F set point. Although Surveyor data indicates that the dust Moon model may be more appropriate for mare areas, it is highly desirable to be able to emplace the PSE on a hard rock surface to improve seismic coupling to the sensor. Thermal control limitations may preclude this.

Work has been continuing toward improving the thermal characteristics of the PSE. During the recent qual B thermal vacuum tests, after deployment the PSE shroud was tucked slightly under the sensor. This reduced the radiative coupling of the sensor base to the lunar surface at night. A report on the results is in process but first look data shows definite improvement in lunar night heater power consumption.

In an independent effort, the P.I. (Dr. G. Latham, Lamont) has contracted with A. D. Little, Inc. (ADL) to look at all thermal test data and give an independent judgment of the adequacy of the thermal control. This report is due by mid-March.

In addition to the possible inadequacy of the thermal control to deal with a "rock" Moon, anamalous rises in temperature were occasionally noted in qual testing. This was originally thought to be spurious commands to the leveling motors (3.6 watts) but was later ascribed to runaway of the thermostat circuitry. A design change has been proposed by BxA, approved by MSC, and will be retrofitted into all flight units. Due to schedule constraints, testing of the change will be on breadboard models.

In general, the PSE thermal control is not optimum. The extent to which its deficiencies will degrade the potential data depends to some extent on the Moon. A "dust" Moon, the most likely, will probably allow 100% data return. Should the conductivity of the surface be significantly higher, however, the temperature set point could not be maintained at night and long period tidal data (not an ALSEP requirement) will be lost or severely degraded. However, one can argue that the sensitivity of the tidal gravity feedback loop is really not high enough (8 μgal) to tell much about the Moon. For example, a sensitivity of 1 μgal is required to differentiate between even grossly differing lunar models (i.e., no liquid core vs. 1/2 of Moon liquid).

Without a constant temperature environment, differential thermal expansion may be a source of noise masking the seismic data. Accuracy of long period (∿100-1000 sec) free oscillation amplitude data will be decreased due to changing spring constants with temperature. This is not particularly worrisome however, since the diagnostic feature of free oscillation data is their frequency, not amplitude.

A more severe data loss would occur should temperature induced tilts or erratic drift require frequent releveling of the horizontal long period sensors. Due to the slow speed of the fine leveling motors this process can take up to two hours for all three long period sensors and result in excessive down-time for the experiment.

2. PSE Caging Subsystem

The second major area that has experienced recurrent problems is the caging subsystem. Due to the fragile suspension systems necessary in any seismometer, pneumatically activated caging is used in the PSE to contrain the seismic masses, booms, and springs. The specified overall leak rate (∿ 10^{-6} cm^3/sec at 343 psi differential pressure) is very stringent due to the two year shelf life requirement. The caging system is a one-shot mechanism with no repressurization or recage capability.

After a series of failures of the caging system to maintain pressure under thermal/vacuum environment, a systematic analysis of the materials and manufacturing procedures revealed certain inadequacies. For example, soft solder had been used in areas that would be under stress and no joints were x-rayed for hidden flaws. Changes in the procedures included hard soldering or brazing joints, better examination of all connections, and changes in assembly procedures to minimize stresses on joints. Retrofit of the new caging system into the Flight I sensor is underway with a schedule completion in early March. After installation, a pre-integration acceptance test will be run and the periods of the seismometers will be rechecked to insure that no damage was incurred during rework.

Qualification of the new system including thermal vacuum, vibration, and shock will be done on the original qual model in parallel with the other flight unit retrofits. This is necessary in order to meet the March delivery of Flight 1 to KSC.

In summary, the problems with the PSE caging system have undergone extensive analysis and a comprehensive program is in progress to ensure satisfactory operation of the flight units. Definite test results on the fixes will be available around the end of March, but the prognosis at present is good.

D. Lunar Surface Magnetometer (LSM)

The objectives of the LSM are to measure the local magnetic field gradients which may be due to nickel-iron and/or stoney-iron meteoric material, and to measure the magnitude, direction, and temporal variation of the equatorial surface magnetic field. Data from the LSM will also be used to derive information on the electrical properties of the deep interior and the interplanetary magnetic field.

There are three modes of operation in the present instrument:

1. Site survey mode: This mode is performed only once on receipt of Earth command when the magnetometer is first put into operation. A site survey is performed along each of the three orthogonal axes by aligning the three sensors parallel to one another successively in the three directions by means of the 90° flip and the 90° gimbal mechanisms. The purpose of the site survey is to identify and locate local lunar surface magnetic sources so that they can be factored into the interpretation of data obtained in the scientific mode.

2. Scientific mode: This is the normal operating mode. The instrument is operated as a magnetic observatory that measures the vector field and the time variation of this field. In this mode the three magnetic sensors are mutually orthogonal.

3. Calibration mode: This is performed automatically at timer-actuated 12 hour intervals but can also be performed by Earth command. The purpose of this operation is to determine the absolute accuracy of the sensors

and correct any drift from the laboratory calibration. This mode of operation is accomplished by the 180° flipping mechanisms.

During the Integrated System Tests (IST) at BxA, the LSM experienced the following failures:

1. Prototype: The z-sensor hung-up during the thermal vacuum test. This failure was later believed to be caused by interference between the electrical and mechanical cables.

2. Qual-model: The z-sensor flipped erratically during the lunar noon IST; however, the problem disappeared during lunar night IST. The erratic behavior of the z-sensor was subsequently not observed during the qual simulation test.

3. Flight I: This unit performed satisfactorily as a measuring device but a series of mechanical problems (such as sensor malfunctions in the B configuration flux tanks where the LSM arms were not fully deployed) were experienced during system level acceptance tests. The Flight 1 unit has subsequently been replaced with the flight spare. An ambient acceptance test at BxA indicated that the flight spare was acceptable for integration into ALSEP I. However, the flight spare has not been subjected to a system level thermal vacuum test (where most LSM problems are observed). A thermal vacuum test on the flight spare is considered a minimal acceptable test to ensure adequate operation on the Moon.

4. Flight II: The y-sensor flipping mechanism was erratic during the thermal vacuum test.

The problems observed in all LSM models are being analyzed by the quality control group at Ames Research Center (ARC). A failure of the sensor 90° flipping or gimbaling mechanism should not significantly degrade the LSM experiment. If, in fact, one of the magnetic sensors failed to flip or gimbal 90°, it will only affect the site survey mode. However, the field gradient measurement can still be achieved with only two sensors if the local field variation is smooth. The scientific mode would not be lost by a failure in the 90° flipping or gimbaling mechanisms since the sensors are initially orthogonal. However, the failure of the 180° flipping mechanism would result in the loss of the calibration mode and subsequent degradation of the data.

All LSM's are calibrated at the GSFC magnetic facilities. Results of the past calibration data will be available soon to interested parties.

E. Solar Wind Spectrometer (SWS)

The SWS is designed to measure energies, densities, incident angles, and temporal variations of solar wind protons and electrons impinging on the lunar surface. The SWS measures 10.5 to 1376 ev electrons and 75 to 9600 ev protons with a minimum flux density of 10^6 particles/cm^2/sec. The SWS has a field of view of 2π steradians and is capable of determining the directions of a collimated solar flux to within 15 degrees. The accuracy of SWS electronic measurements is $\pm$ 4 percent over a 4 decade dynamic range.

The SWS sensor assembly consists of seven modified Faraday cups arranged in a hexagonal cupola configuration. Spring-loaded dust covers protect each sensor from dust and dirt during lunar installation and LM take-off. A retaining cord is melted on Earth command and the dust covers jettisoned.

Relatively few failures have occurred in SWS during the IST at BxA. Most SWS problems were observed in the early models and are listed below:

1. Prototype: A high voltage arcing occurred during the thermal vacuum test. This problem was believed to be caused by outgassing of the instrument and pressure surges in the chamber. This failure has been eliminated by incorporating a high voltage protecting circuit in the instrument.

2. Qual model: The dust cover failed to open during lunar morning IST. Subsequent redesign of the dust cover release mechanism has eliminated this failure. There was a problem of restarting the instrument at lunar morning and lunar night. This failure was caused by the temperature sensor that shuts down the instrument when the temperature drops below a specified value. The problem was resolved by lowering the temperature at which shut down was initiated.

The problems stated above were not observed in the Flight I and Flight II integrated systems tests.

The SWS calibrations are carried out by JPL. The result of the instrument calibration will be kept by the P.I. (Dr. C. Snyder, JPL) for his use only.

F. Suprathermal Ion Detector Experiment (SIDE)/Cold Cathode Gauge Experiment (CCGE)

In the Array A and the Array C configurations, the SIDE and CCGE are combined into one subsystem in order to share common electronics, but in Array B the CCGE is alone.

The SIDE will count the number of low-energy ions in selected velocity and energy intervals over a velocity range of 4×10^4 cm/sec up to 9.35×10^6 cm/sec and an energy range of 0.2 ev to 48.6 ev. The distribution of ion masses up to 120 AMU can be determined from this data. Any local electric fields can be offset by applying an appropriate voltage (up to ± 27.6 v) to a wire mesh ground screen which is emplaced on the lunar surface. Additionally, the SIDE will measure the number of solar wind ions in selected energy intervals between 10 ev and 3500 ev in a separate detector. The mass of these particles cannot be determined because this detector does not employ a velocity filter.

The CCGE will determine the pressure of the ambient lunar atmosphere by measuring the density of neutral atoms and the temperature of the gauge at the time of measurement. The CCGE measurement will also provide an indication of the effects on the lunar atmosphere of contaminants left by the LM and the astronauts and the rate of decay of these contaminants. The CCGE is designed to measure pressures over the range of 10^{-6} torr to 10^{-12} torr.

The Channeltron solid-state detectors in SIDE are operated at -3.5 kv and the anode of the CCGE is set at +4.5 kv. This high voltage difference has repeatedly caused arcing in the instrument. During the integrated system tests at BxA the following problems were observed in the SIDE/CCGE subsystem:

1. Prototype: High voltage arcing occurred during the thermal vacuum test. Initial fault isolation indicated improper grounding. The ground wires in the high voltage circuit were rerouted.

2. Qual model: The instrument arced during temperature transient from night-to-day and day-to-night in the thermal vacuum chamber. This recurrent arcing problem was believed to be caused by outgassing during temperature swings; however, a firm failure analysis was not possible since the instrument was practically destroyed as a result of the chamber implosion during the lunar simulation test.

3. Flight I: High voltage arcing occurred during lunar noon IST (while the instrument was being heated up). This failure was later verified to be due to instrument outgassing.

4. Flight II: The 4.5 kv line was "on" briefly at the beginning of the thermal vacuum test. Repeated attempts throughout the thermal vacuum test failed to turn on the 4.5 kv line again. This failure was later found to be caused by the shorting of the 4.5 kv line by a mounting screw. This instrument is now being reworked at Marshall Laboratory (builder of the SIDE/CCGE subsystem).

The calibration of SIDE instruments is carried out at Rice University under the direction of the P. I., and the calibration of the CCGE is done at Midwest Research Institute with the guidance of the CCGE P. I. Results of these calibration data will be available from the respective P. I.'s.

G. Heat Flow Experiment (HFE)

The HFE will determine the lunar heat flow by measuring the vertical temperature gradient and the thermal conductivity in the near sub-surface. These measurements are accomplished by use of a sausage-like probe, consisting of 2 sections (each 55 cm long), which is lowered to the bottom of a 3 meter hole. A heat sensor-can surrounded by a heater coil is at both ends of each probe section and the cans are separated by a long thermal insulator containing the electrical leads. Each gradient sensor contains two platinum resistance elements. The 4 resistance elements (2 in each can) are connected in an electrical bridge circuit whose off-balance is a measure of the temperature difference between the probe section ends. Both probe sections will measure temperature gradients between 2 K°/m and 0.002 K°/m with a resolution of 0.002 K°/m and between 20 K°/m and 0.020 K°/m with a resolution of 0.020 K°/m. The probe design has proven successful in gradient measurements and tests have shown that the thermometers will maintain their pre-launch calibration through at least one year of lunar operation. The gradient measurement apparatus has encountered no significant problems.

The four heater coils (one wound around each sensor can), ring sensors (located 10 cm from each end of each probe section), and thermometers located within the cans are used to measure thermal conductivity. The thermal conductivity is measured by inducing a known quantity of heat at a known distance from a sensor and measuring the sensor temperature as a function of time. Since the heater coils are radiatively coupled to the drill hole casing, good thermal contact between the casing and the lunar soil is necessary for accurate measurements. In the HFE it was hoped to measure the thermal conductivity _in situ_ to within ± 20% over a dynamic range of 4.2 mW/m-K° to 420 mW/m-K°, and to require 95% core recovery and return from one hole. However, despite considerable effort, the present design has proved to have large axial heat leaks resulting in an analytically intractable model. Therefore, each flight probe is "calibrated" by directly subjecting the probe casing combination to homogeneous materials of known conductivities. Sufficient measurements have been made to verify the validity of this approach and it is estimated that a measurement error as low as 50% can be achieved for the thermal conductivity in the middle of the dynamic range (assuming acceptable Moon-casing thermal contact). There have been no significant problems with the conductivity hardware.

Four thermocouple thermometers are located in the cable between the probe and the lunar surface to measure the sub-surface solar-induced thermal fluctuations and thereby obtain indirect data on the sub-surface stratification and perhaps an average value of thermal diffusivity.

Experimental redundancy is provided by using two holes and making two gradient measurements and 4 conductivity measurements per hole and utilizing the cable thermocouples to investigate sub-surface homogeneity.

The probe has been designed, analyzed, and fabricated by ADL, with work there scheduled to terminate in February 1969. The associated electronics package was designed and fabricated by Gulton Industries, and problems here have been minor and non-recurring (quality control such as chips left in the electronics, EMI shield rupture in shake test, several transistor failures). The electronics includes a unique 13-bit A/D converter (which must be stable for as long as 2.4 seconds), a device which has performed well in test and achieves the required accuracy.

The HFE, however, is hampered by the lack of a drill which is acceptable to the Astronaut Office.

H. Apollo Lunar Surface Drill (ALSD)

The ALSD is a rotary-percussive coring drill built by Martin/Baltimore as a deployment tool/sample collector for the HFE. Initial plans specified that two holes three meters deep and about one inch in diameter would be drilled and cased for the HFE and that the core from the second hole would be returned to earth for stratigraphic analysis and thermal conductivity measurements. (Although core return is not required for the HFE, the earth measurements on the core will provide experimental redundancy.)

The drill program has been relatively trouble-free and successful as far as the hardware and its functional capability are concerned. However, the major interface is with the astronaut since the drill string and both hole-casings are sectional to accommodate astronaut reach and LM stowage. A major rework considerably reduced the number and complexity of required astronaut tasks as well as accommodating altered astronaut reach specifications. Also eliminated was the possibility of accidental astronaut contact with potential hot spots on the drill. Nevertheless, the Astronaut Office considers the drilling task too complex and will not commit to the task as now constituted. MSC is presently reviewing a draft work statement aimed at modification of the drilling task. A suggested mode is to eliminate the drilling and coring operation and instead to use the drill head to sink a stronger hole-casing (higher conductivity boron filament) provided with a suitable penetrating device. MSC estimates that approximately 25 minutes will be required to sink two 3 meter drill stems for the HFE. After the HFE drill stems have been emplaced, the astronaut can then drill a third hole and recover the core for inclusion with the returned lunar samples. The boron filament casing may further degrade the thermal conductivity measurement by introducing a higher conductivity material between the sensor and the Moon. Elimination of the HFE hole core return may weaken the interpretation of the thermal conductivity measurement and degrade the measurement itself by compacting the soil. In addition, it would not be possible to sink the casing through any rock layers.

I. Active Seismic Experiment (ASE)

The ASE is a dual mode experiment consisting of mortar box/grenade launcher, geophone string, detection system (amplifiers, filters, etc.), and thumper (astronaut carried staff containing 21 small explosive charges). During ASE deployment the astronaut uses the thumper to generate seismic waves and and produce data on the very near surface density and layering.

The major portion of the experiment is conducted about 6 months after emplacement. Four explosive grenades are launched to distances from 100 to 1600 m and the resultant ground motion is detected by the geophones. This should produce information on the lunar interior down to depths of 300 to 1000 m. The long quiescent period before activation is to ensure data return from the rest of ALSEP should the grenades misfire. The ASE is scheduled to fly on ALSEP IV only.

Design verification tests of the ASE have been completed with no significant failures. Previous field testing of the mortar box/grenade launch assembly had experienced quality control and manufacturing problems. On the lunar surface the grenade ranges were to have been determined from the initial grenade velocity vector, determined from speed (2 break wires that unreel behind the grenade) and angle (sensors in the mortar box). However, due to aerodynamic effects on the grenades in flight (tumbling, etc.) field testing has been unable to provide the necessary calibration between break wire timing and the initial velocity. The P. I. (Dr. R. Kovach, Stanford) therefore plans to calculate range from time of flight (from a transmitter in the grenade) and angle. He is presently analyzing the errors involved should the grenade be occulted by a local horizon before detonating. He is also continuing work on computer simulations of the dynamics of the break wire spooling problem. The specification on range line determination is to achieve the desired range ± 10% and measure the actual range to 3%. Larger errors will, of course, directly affect the accuracy of the seismic velocity determinations.

A stringent operational requirement on the ASE is the 6 month quiescent survival. An extensive qualification program ensured that the grenade rocket motors would operate after 6 lunar cycles even with their hermetic seals broken. However, no mission simulation or life test has been done on the mortar box which contains the grenade arming and launching electronics as well as the range gate generator, heaters, and controls. During this quiescent period, the mortar box temperature is expected to swing between -76° F and 186° F. A minimum test of the long term operability of the mortar box would be 6 temperature cycles in a vacuum chamber with functional tests before and after the T/V environment. Although this type test has been discussed with MSC and BxA, the present plans for qual and flight acceptance have no provision for life testing the mortar box.

Verification of the ASE/Central Station interface under thermal vacuum conditions will be tested for the first time during the Flight 4 acceptance tests. Due to the 3 channels of high frequency data, the ASE uses a 10 K bits/sec data rate mode as opposed to the usual 1 K bit/sec mode. All other ALSEP experiments are switched to stand-by during the 30 minutes or so of ASE operation. This interface was functionally tested under ambient conditions in prototype testing but, due to hardware limitations, no qual test of the interface under thermal vacuum conditions was performed.

J. Charged Particle Lunar Environment Experiment (CPLEE)

CPLEE consists of two mechanically identical electron-proton spectrometers (or physical analyzers) mounted to point vertically and at 60° off-vertical, respectively. Each spectrometer consists of a set of entrance deflection plates and six Channeltron detectors each with its own amplifiers and counters. Five of the Channeltrons are arranged on one side of the center line of the defection plates and a funnel Channeltron is on the opposite side of the center line. While the five Channeltrons measure particles of a particular polarity in a given energy range, the funnel Channeltron measures particles of opposite polarity in a comparable energy range. The energy and polarity of the particles detected can be varied by changing the amplitude and polarity of the deflection plate voltage. The pulsed output from the Channeltron detectors is then fed through amplifiers and pulse shapers to pulse counters which will be periodically sampled by the data handling system.

The CPLEE was originally proposed to measure the differential energy spectra of electrons and protons from 50 ev to 150 kev in 15 partially overlapping energy levels with a flux from 10^5 to 10^{10} particles/cm^2-sec-str in each Channeltron and a flux of 10^2 to 8×10^2 particles/cm^2-sec-str for the funnel Channeltron. Because of packaging and structural constraints the Channeltrons were moved closer to the deflection plates with a resultant decrease in the energy spectra to 40 ev to 35 kev. By slightly realigning the highest energy Channeltron and instituting continuing checks during assembly of the spectrometers the energy spectra from 40 ev to about 70 kev has been obtained. This spectral region has been deemed acceptable by the P. I. (the P. I. has agreed to accept any spectrometer with an upper energy bandpass greater than 50 kev). Although the energy spectrum sampled by CPLEE partially overlaps the region sampled by the SWS (electrons from 10 ev to 1.375 kev and protons from 75 ev to 9.6 kev), SWS and CPLEE are not in the same ALSEP arrays.

One of the early attractive features of the experiment was the measurement of a wider spectrum of particle flux (i.e., > 100 kev) at the lunar surface but this capability is no longer present. Movement of the last Channeltron closer to the center line of the deflection plates would permit higher energy measurements but would also allow direct UV impingement on the Channeltrons (causing ejection of photoelectrons which the counters could not distinguish from solar wind particles). Therefore, the present CPLEE design is not capable of measuring the higher energy portion of the particle flux.

CPLEE contains two provisions to self-test its own operation:

1. a β source (Ni^{63}) for end-to-end testing before dust cover removal by Earth command.

2. a test oscillator for checking amplifiers and data processing electronics.

The structural, thermal, and electrical design of CPLEE was verified in the Design Verification model and the compatibility of the subsystem with the C/S was verified during the prototype systems test. In addition to the quality control tests on the individual components, the energy passbands of the physical analyzers are determined and the UV noise in the Channeltrons is measured before final assembly of the CPLEE unit. As an assembled unit CPLEE undergoes an acceptance test (in vacuum with high voltages on) at Bendix Research Labs (BRL) to verify that the instrument will respond to C/S commands and that the unit will perform satisfactorily. CPLEE is calibrated at Rice University under the direction of the P. I. and essentially undergoes another electrical functional test. CPLEE does not undergo a thermal test except as a part of the ALSEP systems tests. It appears that the tests performed on CPLEE are adequate to ensure that the unit will operate in the lunar environment, that the unit will respond to C/S commands, and that CPLEE will measure electron fluxes from about 40 ev to 70 kev in 15 partially overlapping energy levels.

In the development and testing of CPLEE various problems have arisen but most have been resolved by design fixes or by modifications in the assembly of the instrument. The only recurrent problem is that of reliability of the operational amplifier modules (Fairchild μA702). Three separate modules failed and six amplifiers operated intermittently at low temperature on the qual model, one amplifier was noisy on the prototype and five amplifiers were intermittent on the qual spare. (This problem has not been observed in either flight unit.) BRL attributes the problem to manufacturing discrepancies in the flatpack itself. The qual model is presently undergoing a seven point test program at BRL to isolate the cause of amplifier failure and until this test plan is complete, CPLEE will not be qualified for flight. A failure analysis is being performed at Fairchild on the amplifier modules which completely failed on the qual model but the study has not been completed.

The failure of a single amplifier module once CPLEE was emplaced would delete any data from that channel in one physical analyzer but would not be a major catastrophy since the same energy interval (but at an angle of 60°) would be sampled by the other physical analyzer.

IV. SUMMARY

Testing of ALSEP Array A has been completed and the flight unit, designated ALSEP I, has been accepted by NASA and is in storage at BxA awaiting rework of the PSE caging subsystem before shipment to KSC in mid-March 1969.

Array B has completed flight acceptance testing and was delivered in February 1969. Array C is undergoing qualification testing and is scheduled for delivery in April 1969.

The RTG per se has no apparent problems but the fuel capsule is designed to rupture along a scored section about eight years after fuel encapsulation and, since fuel capsule deliveries are virtually complete, re-encapsulation may be required for capsules flown after 1974 (an unlikely possibility).

The Central Station analog multiplexer has experienced numerous failures in plastic encapsulated FET semiconductors and PNP transistors during subsystem level tests. An industry survey has located a suitable ceramic hermetically sealed replacement part. The multiplexers in ALSEP III, ALSEP IV, and EASEP, will be reworked but the present rework schedule does not include the ALSEP I multiplexer. Since the analog inputs to the multiplexer consist of housekeeping data only, the failure of this unit on the lunar surface would probably not impact the science return from ALSEP.

The Central Station timer has experienced a series of failures which are due primarily to lubrication problems in the mechanical portions of the unit. An analysis of timer materials, lubricants, and Accutron movements by the Malfunction Analysis Laboratory at KSC resulted in the recommendation of both a different construction material for the indexing wheel and a different lubricant for the wheel-jewels. The ALSEP I timer has been reworked using these materials. Qualification will be done on two reliability timers in parallel with the rework on the other flight units. (This is necessary in order to meet the mid-March delivery of ALSEP I to KSC.) Since the timer is used to initiate specific functions within ALSEP when the uplink is unavailable for any reason, the failure of only the timer would not degrade the scientific data.

The PSE subsystems for which there has been continuing concern are the thermal control subsystem including shroud and temperature controller circuit, and the caging subsystem. The PSE thermal control appears adequate for an insulating ("dust") Moon but may be insufficient for a conducting ("rock") moon. Consequently, it appears that thermal control limitations may preclude placing the PSE on a hard rock surface to improve seismic coupling to the sensor. Work is continuing on this problem, however, and tucking the shroud under the sensor may improve thermal control. An analysis of the problems encountered in the caging subsystem resulted in changes in some manufacturing procedures used in the PSE. The Flight I sensor is being reworked and is scheduled for completion in early March. Qualification of the new system including thermal vacuum, vibration, and shock will be done on the old qual model in parallel with the flight unit retrofits in order to meet the delivery date.

Most of the problems encountered in the LSM have been erratic behavior in the y and z-sensor 90° flipping mechanisms. These failures are currently under analysis by the quality control group at ARC. The Flight I unit has been replaced by the flight spare. However, the flight spare has not been subjected to a system level thermal vacuum acceptance test (where most LSM problems are observed). A systems level thermal vacuum test is considered a minimal test to insure satisfactory operation of the instrument on the Moon.

Relatively few problems have been observed in the SWS. Most SWS problems were observed in the early models and have been resolved. No problems were encountered in the Flight I and Flight II integrated system tests.

The SIDE/CCGE subsystem has experienced high voltage arcing problems. These appear to have been resolved by rerouting ground wires in the high voltage circuitry and allowing sufficient time for outgassing before applying the high voltage.

The HFE has experienced only minor and non-recurring problems (transistor failures, quality control, etc.). There have been no problems with the equipment designed to make either the thermal gradient or conductivity measurements but the interpretation of the conductivity measurements may prove difficult. In addition, the HFE is hampered by the lack of a drill which is acceptable to the Astronaut Office. The Astronaut office considers the drilling task too complex as now constituted and will not commit to it. MSC is currently reviewing a draft work statement aimed at modification of the drilling task.

Previous field testing of the ASE mortar box/grenade launch assembly had experienced quality control and manufacturing problems. The ASE design verification tests have just been completed with no significant failures. No mission simulation or life test has been done, however, on the mortar box which must survive temperature swings between -76°F and 186°F during the six month quiescent period on the lunar surface. Although a minimum test comprising 6 temperature cycles in a vacuum chamber with functional tests before and after the T/V environment has been discussed with MSC and BxA, no provision for life testing the mortar box are included in the present schedule.

Although various problems have arisen during the development and testing of CPLEE most have been resolved by design fixes or modifications in the assembly procedure. The only recurrent problem is that of reliability of operational amplifier modules for which a failure analysis is incomplete. The failure of a single amplifier module once CPLEE was emplaced would delete any data from that channel in one physical anlyzer but would not be a major catastrophy since the same energy interval (but at an angle of 60°) would be sampled by the other physical analyzer.

The recurrent ALSEP problems and the steps being taken to resolve them are summarized in the Abstract Table.

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2015-WLP/GKC/PJH/MTY-kse

Table I

CURRENT ALSEP ARRAYS (1/69)

		ARRAY A* (ALSEP I)	ARRAY B (ALSEP III)	ARRAY C (ALSEP IV)
S031	PASSIVE SEISMIC EXPERIMENT (PSE)	X	X	X
S058	COLD CATHODE GAUGE EXPERIMENT (CCGE)	X	X	X
S036	SUPRATHERMAL ION DETECTOR EXPERIMENT (SIDE)	X		X
S038	SOLAR WIND SPECTROMETER (SWS)	X		
S035	CHARGED PARTICLE LUNAR ENVIRONMENT EXPERIMENT (CPLEE)		X	X
S034	LUNAR SURFACE MAGNETOMETER (LSM)	X		
S037	HEAT FLOW EXPERIMENT (HFE) (INCLUDES APOLLO LUNAR SURFACE DRILL)		X	
S033	ACTIVE SEISMIC EXPERIMENT (ASE)			X

* ALSEP II, also an ARRAY A, has been used in part for the EASEP for the first LM landing.

BELLCOMM, INC.

Subject: ALSEP Status Report

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